

Stem flow chemistry of *Picea glehnii*, *Abies sachalinensis* and *Alnus japonica* and its effect on the peat pore water chemistry in an ombrogenous mire in Ochiishi, eastern Hokkaido, Japan

Tsutomu Iyobe • Akira Haraguchi

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Abstract: We investigated the chemical properties of stemflow of *Picea glehnii*, *Abies sachalinensis* and *Alnus japonica* as well as peat pore water chemistry, including the distance and depth profiles of pore water chemistry, in an ombrogenous mire. The effect of stemflow on the peat pore water chemistry was clear at the stem base in the peat forest in the mire, and the peat pore water around the stem base of a tree had its own chemical properties specific to each species. *P. glehnii* showed the highest concentration of salts both in stemflow and peat-pore water, whereas *A. japonica* showed the lowest concentrations; however, the gradient of the chemical environment from the stem base to outside of the canopy is formed. The peat pore water chemistry under the canopy was mainly controlled by the chemical processes diluted by the abundant peat pore water; the stemflow movement in the high water content of the peat was more slowly because of the flat topography ($< 1^\circ$). This would be due to the fact that the chemicals in stemflow would be diluted by the abundant peat pore water. The spatial heterogeneity of chemical environment between microsites within forested peatland would be also contributed indirectly through the control of microorganism activity, and nutrient regeneration mediated the surface water and the stemflow of the dominant canopy trees.

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Tsutomu Iyobe 

Research Center for Natural Hazards & Disaster Recovery, Niigata University, Ikarashi 2, Nishi-ku, Niigata 950-2181, Japan.

E-mail: iyotsuto@hotmail.com;

Tel.: +81-25-262-7051; Fax: +81-25-262-7050

Akira Haraguchi

Faculty of Environmental Engineering, The University of Kitakyushu, Hibikino 1-1, Wakamatsu, Kitakyushu 808-0135, Japan

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Introduction

In most forest ecosystems, atmospheric precipitation is chemically modified by the canopy of trees (Mahendrappa 1974; Crockford et al. 1996; Chiwa et al. 2003) and the precipitated solution intercepted by the forest canopy affects the soil chemical properties in the forest (Bergkvist and Folkeson 1995; Butler and Likens 1995). Many research efforts have clarified that precipitation is modified by the tree canopies by washing out the deposited substances on the canopy, ionic exchange, or chemical leaching from the leaves (Cappellato and Peters 1995; Houle et al. 1999; Piirainen et al. 2002). Some chemicals deposited on the canopies from the atmosphere are washed out by the precipitated water and these chemicals are enriched in the precipitation through the canopy. The N components ($\text{NO}_3^- + \text{NH}_4^+$) in the precipitation are absorbed by the canopy, and the concentration of nutrients is usually depressed when precipitation is intercepted by the canopy (Lovett and Lindberg 1993); however, in the senescent season, K^+ is leached from the canopy to the precipitation and the nutrients are enriched while precipitated water is being intercepted by the canopy (Lovett and Lindberg 1993; Houle et al. 1999). The interaction between precipitated water and the tree canopy is specific for each tree species (Kaul and Billings 1965; Tajchman et al. 1991; Neary and Gizyn 1994; Gordon et al. 2000). Chemically modified precipitated water reaches the soil surface as throughfall and stemflow and affects the chemical properties of soil. Spatial differences in the precipitated water chemistry and the flux of precipitated water lead to the spatial variability of soil chemical environments in the forest (Potts 1978; Duijsings et al. 1986; Dämmgen and Zimmerling 2002). The precipitated water also affects the vegetation pattern of the forest floor (Clement and Wittig 1987) and soil fauna (Stöckli 1991; Kaneko and Kofuji 2000).

In forest stands, trees can increase the heterogeneity of the

rainwater input process. When precipitation is intercepted by the canopy, it is partitioned into throughfall and stemflow components as diffuse and point inputs, respectively (Chang and Matzner, 2000; Liang et al. 2009). Trees can also increase the heterogeneity of the rainwater infiltration process. Stemflow water flows into soil at the base of tree stems, hence the effects of stemflow extend to a much more restricted area than the effects of throughfall.

Previous studies of soil water dynamics in upland forested stands have paid little attention to the effect of stemflow, due to the low ratio of stemflow to total precipitation. However, the point inflow of stemflow may have major implications for soils water dynamics. Beven and Germann (1982) indicated that macropores in soil may be associated with either living or decayed tree roots and that the structure of macropore systems derived from roots may be very effective at channeling water through the soil. Root-induced channels are preferential flow pathways, and stemflow tends to follow the channels into the soil (Martinez-Meza and Whitford 1996; Voigt 1960). Liang et al. (2009) observed that stemflow rapidly moved into soils layers along pathways around roots. This suggested that stemflow not only serves as a point source of rainwater on the forest floor, but also has a high potential to infiltrate multiple soil layers.

In terrestrial ecosystems, stemflow modifies the chemical properties of soil at the tree base (Jochheim 1984; Förster and Schimmack 1992). Stemflow is enriched with salts or organic substances while flowing through the canopy and stems and carries these chemicals into soils at the stem base. These substances diffuse or flow from the stem base to the surrounding soil. In particular, the acid deposition is concentrated in the stemflow and highly acidified stemflow affects the soil chemistry (Falkengren-Grerup and Björk 1991; Joslin and Wolfe 1992; Bini and Bresolin 1998; Kaneko and Kofuji 2000; Matschonet and Falkengren-Grerup 2000). Many researchers have shown that stemflow strongly affects the soil chemistry at the stem base and that a clear gradient of chemical properties appears around the stem base (Gersper and Holowaychuk 1971; Chang and Matzner 2000). Some researchers have also analyzed the process of matter flux from the atmosphere to a limnological system via vegetation and soil (Stevens et al. 1989; Neal et al. 2003).

Peat bogs support a mosaic vegetation types that is largely determined by differences in water level and nutrient content. Some area is open and dominated by *Sphagnum* spp. whereas others may be forested with single or several tree species (Ahmad-Shah and Rieley 1989; Haraguchi et al. 2003; Iyobe and Haraguchi 2008). Stemflow might also induce spatial heterogeneity of soil solution and of water and element fluxes in the mire soil. The spatial heterogeneity of soil solution chemistry and water fluxes caused by stemflow is likely to be influencing stand-level elemental budgeting.

The evergreen needle-leaved tree *P. glehnii* Masters and the deciduous broad-leaved tree *A. japonica* form wetland forests in Hokkaido, northern Japan (Tomizawa et al. 1997; Hotes et al. 2001; Haraguchi et al. 2003; Tsuyuzaki and Haraguchi 2009). The two species have contrast and specific characteristics, i.e., *P. glehnii* produce acidic soil environment (Haraguchi et al. 2003)

and *A. japonica* is nitrogen-fixing plant. *Abies sachalinensis* Masters, evergreen needle-leaved, is also abundant species in Hokkaido. At a *P. glehnii* - *A. sachalinensis* forests on coastal sand dune in eastern Hokkaido, Nishijima et al. (2003) reported the boundary between the *P. glehnii* and *A. sachalinensis* forests is determined by the ground-water table depth and the pH of the soil pore water with groundwater dynamics caused by the difference of microtopography. If these forest stands established on the saturated soil on the flat topography, effects of chemicals in stem flow on soil chemical properties under the tree canopy would be dependent on the rate of diffusion and flux within the inundated soil. However, research on the precipitation chemistry in wetland forests is not so extensive, and information on the effects of stem flow on the inundated soil chemical environment is scarce.

In this study, we focused on the effects of stem flow on the soil chemical environment in a boreal forested peatland. We determined the chemical properties of stemflow of three common species as well as peat pore water chemistry, including the distance and depth profiles of pore water chemistry. The objectives of this study were (1) to evaluate how stemflow chemistry affects the soil chemical environment and (2) to evaluate the species differences in modification of peat chemistry by stemflow.

Study area and methods

Study area

The study area was in Ochiishi district (43°10–13' N, 145°28–31' E), Nemuro City, eastern Hokkaido, northern Japan. In the Ochiishi district, there are some peat mires (5–65 ha) on the Upper Pleistocene coastal terrace, ca. 50 m a.s.l. More specifically, the study was carried out at the Cape Ochiishi Mire. Cape Ochiishi Mire (61.3 ha) is on the Nemuro peninsula and faces the coastline from a distance of 0.4 km or less. The annual temperature, rainfall, and humidity from 1961 to 1990 in the district averaged 5.9°C, 1035 mm, and 80%, respectively (reports from the meteorological observatory in Nemuro City). From late spring to mid summer, this area is covered with sea fog carried by wind originating in the south above the Pacific Ocean. The fog formation process in this region is described in detail by Hori (1953).

The peat depth is ca. 2.0–3.0 m in Cape Ochiishi Mire (Iyobe et al., unpublished data). Volcanic ash has fallen on these mires several times. In these mires, the uppermost tephra (aerially transported volcanic ejecta) layer, which was easily detectable in the cores between a peat stratigraphic depth of 10 to 15 cm, corresponds with the Me-a (Meakan tephra layer: ca. 500 year BP, Iyobe and Haraguchi 2005). Cape Ochiishi Mire is on a cape connected by low-lying land with the mainland and is almost completely surrounded by the Pacific Ocean.

The dominant plant species in Cape Ochiishi Mire are *Sphagnum* spp. and *Picea glehnii* (Fr. Schm.) Masters, *Abies sachalinensis* (Fr. Schm.) Masters, *Alnus japonica* (Thunb.) Steud. The *P. glehnii* trees grow on the margins of the *Sphagnum*-dominated

mires. The peat surface exhibits a well-developed hummock-hollow microtopography. The *P. glehnii* trees in the transition zone are stunted and distorted. The surrounding area in Cape Ochiishi Mire is dominated by the *A. japonica* trees. These forest canopies are almost monospecific. *A. sachalinensis* is established between the *P. glehnii* and *A. japonica* trees zone, which is mixed with *P. glehnii* trees. The *Sphagnum* mire is dominated by *Sphagnum fuscum* (Schimp.) Klinggr., *Empetrum nigrum* L. var. *japonicum* K. Koch, and *Vaccinium oxycoccus* L. In the forest, *Lysichiton camtschatcense* (L.) Schott, *Ledum palustre* L. spp. *diversipilosum* (Nakai) Hara and *Sphagnum* spp. (mainly *S. girgensohnii* Russ. and *S. squarrosum* Crome.) dominate the understory (Haraguchi 1996).

Stemflow chemistry

Stemflow collectors were made of polyethylene tubing (2-m long and 1-cm diameter) cut longitudinally in half. The tubes encircled the lower bole of the tree trunks. Stemflow was collected in 5-L polyethylene bottles. Two individuals (6 to 7 m high and 20 to 25 cm d.b.h.) of three species, *P. glehnii*, *A. sachalinensis* and *A. japonica* were selected in the Cape Ochiishi mire and stemflow collectors were placed on the 6 individuals (3 species \times 2 individuals) on 5 June 2001. Stemflow samples were collected at biweekly from June 15 to December 1, 2001 (total: 13 times). Stemflow samples were transferred to 100 mL polyethylene bottles after the volume of stemflow was measured in the field. Samples were stored in dark, cool conditions before analyses.

Electrical conductivity (EC) and pH were measured in the laboratory within 24 h after sampling with portable EC and pH meters (TOA Co., Tokyo, Japan). The values for EC were not corrected for pH. Samples for ion analysis were filtered through a nitrocellulose membrane filter (0.20 μ m, Advantec Toyo Co., Tokyo, Japan type DISMIC-25CS) within 24 h after sampling and stored in a freezer (−18 °C) to reduce microbial activity. The major cations (NH_4^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+}) and major anions (Cl^- , NO_3^- , NO_2^- , SO_4^{2-} , PO_4^{3-}) were then analyzed by an ion chromatograph (Japan Dionex, Tokyo, Japan, model DX-500).

Chemistry of peat pore water

Peat pore water was collected from collectors made of 1-cm-diameter polyethylene pipe fitted with a porous ceramic cup. The sample collectors were inserted vertically to just below the ground surface (0 cm depth), 30 cm depth and 60 cm depth at points just beside the tree stem (N site) and 50 cm from the tree stem (F site) for each of the individuals with a stemflow collector (3 species \times 2 distances \times 3 depths \times 2 individuals). We placed other collectors for peat pore water sampling within the *Sphagnum*-dominated community (open site) at just below the ground surface (0 cm depth), 30 cm depth and 60 cm depth (3 depths \times 2 individuals). The water was collected by a suction pump that reduced pressure to 60 mm Hg in the pipe. To avoid contamination with stagnant water in the collector, the first 100-ml sample was discarded, and the subsequent 100-ml sample was collected in a polyethylene bottle. Samples were stored in dark cool condi-

tions before analysis. Water samplings and chemical measurements of the peat pore water were made biweekly from July 15 to November 22, 2001 (total: 18 times).

EC and pH were measured in the laboratory within 24 h after sample collection. Concentrations of the major cations (NH_4^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+}) and major anions (Cl^- , NO_3^- , NO_2^- , SO_4^{2-} , PO_4^{3-}) were determined as for the stemflow analysis after filtering through a nitrocellulose membrane filter (0.20 μ m).

Statistical analysis

The Wilcoxon signed-rank test was performed on the stemflow chemical data to evaluate the species differences. Differences in peat pore water chemistry among three species at each depth were also tested using the Wilcoxon signed-rank test. Differences among the three depths of peat pore water for each species were evaluated using the Friedman test. Principal component analysis (PCA) by correlation matrix was performed on the averaged peat chemical data to show the similarities of chemical properties among various sampling points and water types, including stemflow and peat pore water.

Results

Stemflow chemistry

The water quantity in stemflow did not show any significant difference among the three species (Table 1). Proton (H^+), Mg^{2+} and Ca^{2+} concentrations in stemflow showed significant differences among the three species in a decreasing order: *P. glehnii* $>$ *A. sachalinensis* $>$ *A. japonica*. Electrical conductivity (EC), Na^+ , K^+ , Cl^- and SO_4^{2-} concentrations in the stemflow of conifers (*P. glehnii* and *A. sachalinensis*) were significantly higher than that of *A. japonica*. PO_4^{3-} concentration of the stemflow of *A. sachalinensis* was significantly higher than was the case with the other two species. NH_4^+ and NO_3^- concentrations in the stemflow did not show significant differences among the species. NO_2^- was always below the detection limit (0.01 $\mu\text{mol}_\text{c} \cdot \text{L}^{-1}$).

Species difference of peat pore water chemistry

At the surface of the peat (0 cm depth), EC at the stem base of *P. glehnii* was significantly higher than in the case of *A. japonica* (Fig. 1). H^+ concentration of the peat pore water at 0 cm depth at the stem base of the conifers was significantly higher than that of *A. japonica*. NH_4^+ , Mg^{2+} and Cl^- concentrations at the 0 cm depth at the stem base of *P. glehnii* were significantly higher than were those of the other two species. Na^+ , K^+ , Ca^{2+} , NO_3^- , PO_4^{3-} and SO_4^{2-} concentrations of the peat surface at the stem base did not show significant differences among the three species. NO_2^- was always below the detection limit (0.01 $\mu\text{mol}_\text{c} \cdot \text{L}^{-1}$).

EC and the Cl^- concentration at the 30 cm depth at the stem base showed a significant decreasing order: *P. glehnii* $>$ *A. sachalinensis* $>$ *A. japonica* (Fig. 1). Na^+ concentration at the 30 cm depth at the stem base of the conifers was significantly higher

than that of *A. japonica*. NH_4^+ , Mg^{2+} and SO_4^{2-} concentrations at the 30 cm depth at the stem base of *P. glehnii* were significantly higher than were those of the other two species. Ca^{2+} concentration at the 30 cm depth at the stem base of *P. glehnii* was significantly higher than in the case of *A. sacharinensis*. K^+ concentration at the 30 cm depth at the stem base of *A. sacharinensis* was

significantly higher than for the other two species. PO_4^{3-} concentration at the 30 cm depth at the stem base of *P. glehnii* was significantly lower than in the case of *A. japonica*. H^+ and NO_3^- concentrations at 30 cm depth at the stem base did not show significant differences among the three species.

Table 1. Chemical property (mean and SD) of stem flow of *Picea glehnii* (PG), *Abies sacharinensis* (AS) and *Alnus japonica* (AJ) in Cape Ochiishi Mire, eastern Hokkaido, Japan. Data were collected 13 times from 15 July to 1 December 2001 at regular intervals. Significance level; ** $p < 0.01$, * $p < 0.05$, NS not significant $p > 0.05$. SD: standard deviation, EC: electric conductivity

Species			Chemical property											
			Water	EC	H ⁺	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
			mL · interval ⁻¹	mS·m ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹	mol _e ·L ⁻¹
<i>P. glehnii</i>	Mean±		3695±	31.8±	72.6±	10.74±	1471.36±	284.34±	431.4±	458.98±	2608.15±	0.17±	0.06±	298.08±
	SD		6634	15.62	44.4	14.16	810.96	126.6	285.74	300.51	1670.51	0.38	0.21	175.52
<i>A. sacharinensi</i>	Mean±		2624±	33.03±	28.85±	17.01±	1054.84±	235.06±	201.17±	163.88±	1630.57±	0.06±	47.7±	194.1±
<i>s</i>	SD		3924	22.95	23.82	30.02	708.12	155.47	188.6	129.21	1279.89	0.13	56.49	162.69
<i>A.. japonica</i>	Mean±		2373±	7.25±	21.45±	14.21±	375.32±	48.94±	79.22±	44.32±	515.93±	D.L.*	D.L.	53.52±
	SD		1627	5.8	9.83	9.83	313.7	33.97	76.8	37.5	514.56			41.62
Significance	(Wilcoxon	PG - AS	NS	NS	**	NS	NS	NS	*	**	NS	NS	*	NS
level	signed-rank	PG - AJ	NS	**	**	NS	**	**	**	**	**	NS	NS	**
	test)	AS - AJ	NS	*	*	NS	**	**	**	**	**	NS	*	**

*: below the detection limit ($0.01 \mu\text{mol}_e \cdot \text{L}^{-1}$)

EC and the NH_4^+ , Mg^{2+} and Cl^- concentrations at the 60 cm depth at the stem base showed a significant decreasing order: *P. glehnii* > *A. sacharinensis* > *A. japonica* (Fig. 1). Na^+ and Ca^{2+} concentrations at the 60 cm depth at the stem base of the conifers were significantly higher than those of *A. japonica*. H^+ and SO_4^{2-} concentrations at the 60 cm depth at the stem base of *P. glehnii* were significantly higher than with the other two species. NO_3^- concentration at the 60 cm depth at the stem base of *P. glehnii* was significantly higher than in the case of *A. sacharinensis*. PO_4^{3-} concentration at the 60 cm depth at the stem base of *A. sacharinensis* was significantly lower than that for *A. japonica*. K^+ concentrations at 60 cm depth at the stem base did not show significant differences among the three species.

Vertical profile of peat pore water chemistry

Electrical conductivity (EC) of the peat pore water significantly increased from the top to the 60 cm depth for all the three species (Fig. 1). H^+ concentration significantly decreased from the top (0 cm) to the 60 cm depth for *P. glehnii*, *A. sacharinensis* and *A. japonica*.

In the vicinity of the two coniferous species *P. glehnii* and *A. sachalinensis*, NH_4^+ , Na^+ , Mg^{2+} and Ca^{2+} concentrations significantly increased from the top to the 60 cm depth, whereas K^+ did not show significant difference among depths for these two species (Fig. 1). In the vicinity of *A. japonica*, Na^+ and Mg^{2+} showed significant differences among depths and the concentration at 30 cm depth was the minimum. Ca^{2+} also showed significant differences among depths for *A. japonica* and the concentration at 30 cm depth was the maximum. NH_4^+ and K^+ did not show significant differences among depths in the vicinity of *A.*

japonica.

Among anions, Cl^- showed significant differences between depths for the three species, and the Cl^- concentration showed a tendency to increase from the top to the 60 cm depth, with the exception of *A. japonica*, which showed a minimum at 30 cm depth. PO_4^{3-} concentration showed significant differences among depths only for *A. japonica*, showing a maximum concentration at 30 cm depth (Fig. 1). NO_3^- and SO_4^{2-} concentration did not show significant differences among depths for the three species.

Difference of peat pore water chemistry between under canopy and open site

EC and H^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+} concentrations of the peat pore water at the stem base (either or both the N and F sites) were significantly higher than at the corresponding depth in the open sites, for all species and for all depths of the peat (Table 2). NH_4^+ concentrations at the stem base (either or both the N and F sites) of *P. glehnii* were significantly higher than results at the corresponding depth in the open sites for all depths of the peat, whereas the difference was significant at 30 cm depth for *A. sacharinensis* (stem base > open site). The concentration of NH_4^+ at the stem base of *A. japonica* (either or both the N and F sites) showed significant difference from the open site at all the depths; however, the difference did not show a consistent trend between open sites and stem base. Cl^- concentrations at the stem base (either or both the N and F sites) were significantly higher than at the open site for *P. glehnii* at 30 cm and 60 cm depths, for *A. sacharinensis* at 60 cm, and for *A. japonica* for all depths. NO_3^- concentration did not show significant difference between the stem base and the open site, for all species and all depths. PO_4^{3-}

concentrations at the stem base (either or both the N and F sites) of *A. japonica* were significantly higher than at the open site at 30 cm and 60 cm depths. SO_4^{2-} concentrations at the stem base were significantly higher than at the open site, except for *A. sacharinensis* at 0 cm depth (open site > stem base) and for *A. japonica* at 0 cm (open site > stem base) and 30 cm depths.

Peat pore water chemistry along the distance from the tree stem base

Differences of peat pore water chemistry between stem base (N site) and 50 cm from the stem base (F site) of *P. glehnii* showed significant differences in Ca^{2+} at 0 cm depth (N>F), in SO_4^{2-} at 30 cm and 60 cm depths (N<F), and in H^+ and K^+ at 60 cm depth (N<F) (Table 2). For *A. sacharinensis*, peat pore water showed significant differences between N and F sites in EC (N<F), H^+ (N>F), Na^+ (N<F), Mg^{2+} (N<F), Ca^{2+} (N<F), Cl^- (N<F), SO_4^{2-} (N<F) at 30 cm depth, and in Na^+ (N<F), K^+ (N>F), Ca^{2+} (N>F) at 60 cm depth (Table 2). For *A. japonica*, EC of the peat pore water showed significant differences between N and F sites (N>F) at 0, 30 and 60 cm depths. Peat pore water showed significant differences between N and F sites in Cl^- (N<F) at 0 cm depth, Mg^{2+} (N>F), Ca^{2+} (N>F), SO_4^{2-} (N<F) at 30 cm depth,

and in PO_4^{3-} (N<F) at 60 cm depth (Table 2).

Ordination by the principal component analysis (PCA)

Eigenvalues of the first and second principal components calculated using a correlation matrix were 5.41 and 1.57, respectively, and their proportions were 60.1 % and 17.5 %, respectively. Stemflow chemistry of the three species was distributed on the first principal component axis (Fig. 2a). Stemflow of *P. glehnii* had the highest and that of *A. japonica* had the lowest score for the first principal component. Peat pore water chemistry in the vicinity of the three species was distributed on the first principal component axis, and higher scores resulted than that at the open site. Among the peat pore water results near the three species, *P. glehnii* had the highest and *A. japonica* had the lowest score on the first principal component axis. Although there was not discernible difference at various depths for the peat pore water in the open site, the peat pore water at the three depths in close proximity to the three species distributed on the second principal component axis. Peat pore water at the peat surface had the lowest and that at the 60 cm depth had the highest score on the second principal component axis.

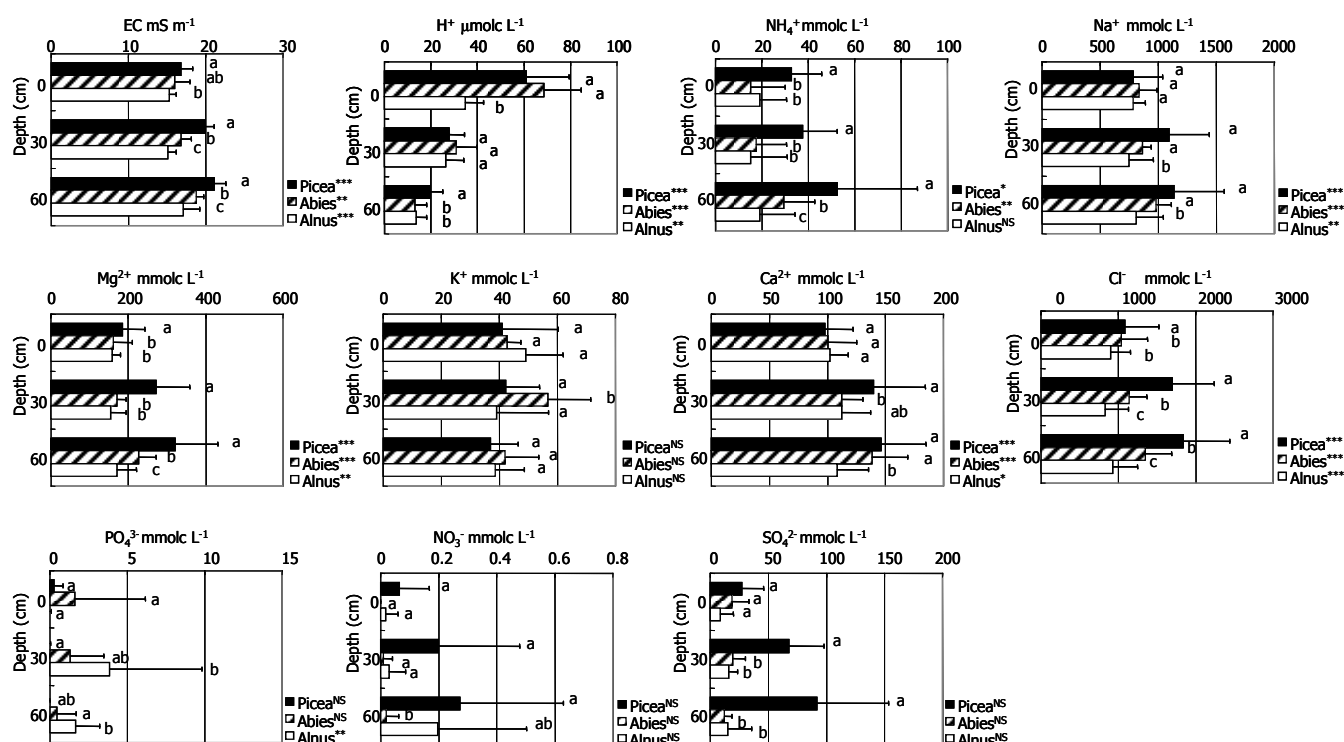


Fig. 1 Means (bars) and SD (error bars) of the electric conductivity (EC), ion concentrations of proton, ammonium, sodium, magnesium, potassium, calcium, chloride ion concentrations, phosphate, nitrate and sulfate in peat pore water at surface (0 cm), 30 cm and 60 cm depths from the peat surface around *Picea glehnii* (closed bars), *Abies sacharinensis* (hatched bars) and *Alnus japonica* (open bars) in the forest mire in Cape Ochiishi, eastern Hokkaido, Japan. Water samplings and chemical measurements of the peat pore water were made 18 times from 15 July to 22 November 2001 at regular intervals. Means sharing the same alphabetical letter does not significantly different between species at each depth by Wilcoxon test at $p < 0.05$ ($n=18$). Significance level by Friedman test among three depth for each species are; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS $p > 0.05$.

Table 2 Chemical property (mean and SD) of peat pore water at three depths (0 cm, 30 cm, 60 cm) under the canopy of *Picea glehnii*, *Abies sacharinensis* and *Alnus japonica* in the Cape Ochiishi Mire, eastern Hokkaido, Japan. Water samplings and chemical measurements of the peat pore water were made 18 times from 15 July to 22 November 2001 at regular intervals. N and F sites denote 0 cm and 50 cm from each stem base, respectively. Open site is in the *Sphagnum* community outside the forest. Significance level; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS not significant $p > 0.05$. SD: standard deviation, EC: electric conductivity

Species			Chemical property										
<i>Picea glehnii</i>			EC	H ⁺	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
			mS m ⁻¹	mol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹
0 cm													
N site	Mean ±		17.15±	81.02±	39.17±	813.15±	38.54±	195.81±	107.4±	1156.28±	0.11±	D.L.*	26.96±
	SD		1.66	20.79	19.79	293.13	10.72	56.67	24.1	442.89	0.3		27.33
F site	Mean		16.47±	72.24±	26.03±	849.67±	50.28±	198.44±	95.72±	1162.99±	0.04±	0.63±	32.6±
	SD		3.3	26.7	26.32	285.23	38.21	65.38	31.64	496.06	0.16	1.75	28.88
Open site	Mean		7.6±	18.21±	17.48±	401.87±	12.22±	84.89±	50.22±	532.38±	0.51±	D.L	22.3±
	SD		1.51	6.24	10.5	123.33	5.64	31.11	17.91	211.74	0.79		16.85
Significance level	(Wilcoxon	N - F	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
	signed-rank	N - Open	*	*	**	**	**	**	**	NS	NS	NS	**
	test)	F - Open	*	***	NS	**	***	***	**	NS	NS	NS	**
30 cm													
N site	Mean±		19.66±	27.89±	47.61±	996.52±	56.39±	219.1±	130.1±	1636.11±	0.47±	D.L.	28.53±
	SD		1.92	11.24	45.48	437.62	30.14	78.96	40.51	551.15	0.69		19.42
F site	Mean±		19.73±	28.44±	33.44±	1146.78±	39.07±	287.36±	151.76±	1741.51±	0.07±	0.03±	102.97±
	SD		2.12	11.3	21.51	391.23	13.81	103.1	93.69	631.35	0.2	0.14	96.02
Open site	Mean±		8.04±	2.17±	16.9±	432.47±	9.36±	82.3±	60.34±	519.34±	0.28±	D.L	8.93±
	SD		1.33	1.37	13.29	164.99	9.9	32.51	14.81	250.09	0.47		8.58
Significance level	(Wilcoxon	N - F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
	signed-rank	N - Open	**	***	*	**	**	**	**	**	NS	NS	**
	test)	F - Open	**	***	NS	**	**	**	**	*	NS	NS	**
60 cm													
N site	Mean±		20.06±	21.05±	42.25±	1089.7±	37.42±	285.5±	139.15±	1761±	0.41±	D.L	42.78±
	SD		1.72	11.73	31.77	435.7	19.8	102.81	39.86	648.24	0.76		58.85
F site	Mean±		22.04±	24.22±	62.08±	1114.56±	44.08±	327.85±	142.82v	1805.25±	0.08±	D.L	131.37v
	SD		1.51	13.21	94.58	490.72	13.03	118.37	36.98	635.91	0.24		140.8
Open site	Mean±		8.86±	4.21±	17.56±	411.5±	14.52±	77.34±	61.1±	510.86±	0.29±	0.15±	4.27±
	SD		1.09	2.04	7.32	78.22	21.26	16.08	19.23	116.17	0.62	0.48	3.61
Significance level	(Wilcoxon	N - F	NS	*	NS	NS	***	NS	NS	NS	NS	NS	*
	signed-rank	N - Open	**	***	**	***	**	***	***	**	NS	NS	***
	test)	F - Open	**	***	**	**	**	***	***	**	NS	NS	***

Species			Chemical property										
<i>Abies sacharinensis</i>			EC	H ⁺	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
			mS m ⁻¹	mol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹
0 cm													
N site	Mean±		16.25±	72.4±	14.69±	843.48±	48.09±	163.18±	96.69±	1047.28±	D.L	3.57±	15.66±
	SD		1.28	20.81	17.76	135.48	12.11	52.55	25.33	350.35		11.61	14.22
F site	Mean±		15.67±	65.77±	14.12±	821.57±	38.93±	156.05±	100.35±	1015.45±	D.L	D.L	19.76±
	SD		2.46	14.87	17.12	171.32	9.49	51.61	24.56	344.24			17.62
Open site	Mean±		7.6±	18.21±	17.48±	401.87±	12.22±	84.89±	50.22±	532.38±	0.51±	D.L	22.3±
	SD		1.51	6.24	10.5	123.33	5.64	31.11	17.91	211.74	0.79		16.85
Significance level	(Wilcoxon	N - F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	signed-rank	N- Open	*	**	NS	**	**	**	**	NS	NS	NS	**
	test)	F - Open	*	***	NS	***	NS	***	**	NS	NS	NS	**
30 cm													
N site	Mean±		16.03±	40.18±	13.76±	780.62±	49.12±	139.25±	99.17±	917.03±	D.L	1.43±	16.99±
	SD		1.23	11.65	17.07	113.84	12.21	28.13	20.18	236.58		3.51	13.01
F site	Mean+		17.72+	18.8+	20.21+	941.43+	65.96+	197.28+	122.47+	1314+	0.02+	1.23+	21.77+

Continue Table 2

	SD		2.07	13.53	20.64	174.11	39.58	44.06	30.18	393.84	0.09	3.2	31.46
Open site	Mean±		8.04±	2.17±	16.9±	432.47±	9.36±	82.3±	60.34±	519.34±	0.28±	D.L.	8.93±
	SD		1.33	1.37	13.29	164.99	9.9	32.51	14.81	250.09	0.47		8.58
Significance level	(Wilcoxon signed-rank test)	N - F	**	**	NS	**	NS	**	*	**	NS	NS	*
		N - Open	**	***	NS	***	**	**	**	NS	NS	NS	**
		F - Open	**	***	NS	***	**	**	**	NS	NS	NS	**
60 cm													
N site	Mean±		18.88±	11.77±	24.53±	943.31±	45.21±	221.23±	139.33±	1265.23±	0.01±	0.08±	12.91±
	SD		1.98	8.42	25.92	179.35	14.04	52.94	33.37	331.98	0.06	0.23	13.59
F site	Mean±		18.43±	14.03±	34.87±	998.62±	39.05±	222.05±	132.2±	1329.62±	0.03±	0.9±	12.02±
	SD		1.98	6.88	17.27	145.71	31.02	42.87	29.13	329.86	0.12	3.61	12.18
Open site	Mean±		8.86±	4.21±	17.56±	411.5±	14.52±	77.34±	61.1±	510.86±	0.29±	0.15±	4.27±
	SD		1.09	2.04	7.32	78.22	21.26	16.08	19.23	116.17	0.62	0.48	3.61
Significance level	(Wilcoxon signed-rank test)	N - F	NS	NS	NS	*	**	NS	***	NS	NS	NS	NS
		N - Open	**	***	NS	***	***	***	***	**	NS	NS	***
		F - Open	**	***	***	***	***	***	***	*	NS	NS	***
Species													
<i>Alnus japonica</i>			Chemical property										
			EC	H ⁺	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
			mS m ⁻¹	mol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹	mmol _c ·L ⁻¹
0 cm													
N site	Mean±		15.65±	37.35±	15.67±	773.37±	48.86±	155.39±	100.14±	875.34±	0.03±	D.L.	8.02±
	SD		1	8.77	17.35	104.74	12.34	21.45	16.32	269.87	0.13		12.77
F site	Mean±		14.9±	33.39±	22.7±	793.91±	49.36±	159.04±	104.5±	915.45±	D.L.	0.04±	9.49±
	SD		1.23	13.3	19.31	111.68	19.24	25.52	18.31	254.44		0.16	25.42
Open site	Mean±		7.6±	18.21±	17.48±	401.87±	12.22±	84.89±	50.22±	532.38±	0.51±	D.L.	22.3±
	SD		1.51	6.24	10.5	123.33	5.64	31.11	17.91	211.74	0.79		16.85
Significance level	(Wilcoxon signed-rank test)	N - F	*	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
		N - Open	*	**	***	**	***	NS	**	**	NS	NS	***
		F - Open	*	**	NS	**	***	*	**	NS	NS	NS	**
30 cm													
N site	Mean±		15.68±	24.61±	15.39±	771.6±	38.98±	167.82±	121.21±	869.11±	D.L.	1.47±	3.39±
	SD		1.4	8.34	20.6	248.7	26.19	68.21	42.36	330.43		3.06	4.1
F site	Mean±		14.56±	27.78±	14.97±	718.65±	39.07±	139.87±	104.02±	790.85±	0.06±	6.17±	27.61±
	SD		1.19	18.55	17.95	204.66	19.7	37.06	24.03	280.06	0.17	17.7	30.92
Open site	Mean±		8.04±	2.17±	16.9±	432.47±	9.36±	82.3±	60.34±	519.34±	0.28±	D.L.	8.93±
	SD		1.33	1.37	13.29	164.99	9.9	32.51	14.81	250.09	0.47		8.58
Significance level	(Wilcoxon signed-rank test)	N - F	**	NS	NS	NS	NS	*	*	NS	NS	NS	*
		N - Open	**	***	***	***	***	**	**	NS	NS	*	**
		F - Open	**	***	NS	***	***	**	**	*	NS	*	**
60 cm													
N site	Mean±		18.11±	13.19±	23.27±	803.2±	29.94±	168.89±	103.67±	924.11±	0.11±	D.L.	19±
	SD		2.51	7.29	22.64	247.97	10.41	53.08	29.57	346.69	0.47		36.96
F site	Mean±		16.2±	13.33±	14.81±	812.21±	47.4±	173.29±	112.14±	929.34±	0.28±	3.27±	11.41±
	SD		2.32	8.52	21.85	223.91	37.15	57.12	31.83	326.2	0.64	5.51	21.76
Open site	Mean±		8.86±	4.21±	17.56±	411.5±	14.52±	77.34±	61.1±	510.86±	0.29±	0.15±	4.27±
	SD		1.09	2.04	7.32	78.22	21.26	16.08	19.23	116.17	0.62	0.48	3.61
Significance level	(Wilcoxon signed-rank test)	N - F	**	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
		N - Open	**	***	***	***	***	***	***	**	NS	*	***
		F - Open	**	***	***	***	***	***	***	NS	NS	NS	***

*: below the detection limit (0.01 μmol_c·L⁻¹).

Most of the ion species except for NH₄⁺ and NO₃⁻ concentrations had positive loadings for the first principal component, whereas NO₃⁻ concentration had negative loadings for the first

principal component (Fig. 2b). NH₄⁺ and NO₃⁻ concentrations had positive loadings for the second principal component, whereas H⁺ concentration had negative loading for the second

principal component.

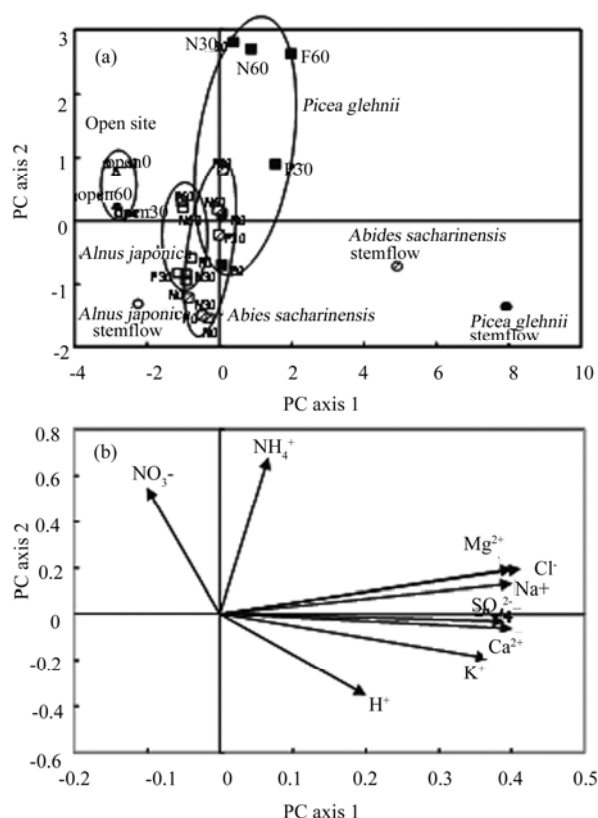


Fig. 2 (a) Ordination by principal component analysis (PCA) using first and second principal component scores at each sampling point. N and F denote the distance from the stem base of 0 cm (N) and 50 cm (F), respectively. 'Open' denotes the open site outside the forest. The following number of 0, 30, and 60 denote the depth of the sampling point in cm. Closed square: peat pore water at the base of *Picea glehnii*, Hatched square: peat pore water at the base of *Abies sachalinensis*, Open square: peat pore water at the base of *Alnus japonica*, Open triangle: peat pore water at the open site, Closed circle: stemflow of *Picea glehnii*, Hatched circle: stemflow of *Abies sachalinensis*, Open circle: stemflow of *Alnus japonica*, and (b) loadings on the first and second principal component scores of each chemical parameter used in the PCA.

Discussion

The bulk deposition in the Cape Ochiishi Mire was 637 mm from June 15 to December 1, 2001. The distribution ratio of the stemflow to the bulk deposition was estimated to be 0.19%, 0.12%, and 0.57%, respectively, in the *Picea glehnii*, *Abies sachalinensis*, and *Alnus japonica*. This result was representative of forest types. Capturing ability of precipitation was greater in coniferous canopy due to the higher interception within the canopy and to the conifer morphology. The lower volume observed in the coniferous stand was probably due to branch disposition and greater trunk surface roughness.

Three mire species were distinguished using principal compo-

nent analysis of the chemical composition of stemflow (Fig. 2). Most ion concentrations including sea salt components had positive loadings for the first principal component, and hence the stemflow of *P. glehnii* was affected by the highest salt loading and that of the *A. japonica* was affected by the lowest salt loading to the stemflow. The differences in the salt loadings among the species would be due to the differences in the canopy structure. Coniferous species canopies usually have a higher ability to capture atmospheric deposition than hardwood, and as a consequence throughfall and stemflow of conifers usually contain higher concentrations of salts and H^+ (Kaul and Billings 1965; Mahendrappa 1974; Neary and Gizyn 1994; Bergkvist and Folkesson 1995). In Cape Ochiishi Mire, the H^+ concentrations in the stemflow of *P. glehnii* and *A. sachalinensis* were higher than in *A. japonica* trees is in good agreement with these published results.

Although the differences in peat pore water chemistry among the three species was not so clearly separated by PCA, the distribution order of the peat pore water of the three species matched the order of the stem flow of the three species: *P. glehnii* had the highest and *A. japonica* had the lowest score on the first principal component axis for both the stem flow and peat pore water (Fig. 2). Chemical environment in the peat soils were different between coniferous and broadleaf forests, and a part of the difference could be explained by the chemical properties of stemflow. Tsuyuzaki and Haraguchi (2009) demonstrated that the chemical difference in the peat soil environments between *P. glehnii* and *A. japonica* affects both the seed germination and seed survival and consequence an abrupt boundary is developed between them. Therefore, the maintenance of chemical environments could be important on the stability of the communities. Our study shows that stemflow contribute the maintenance of communities because stemflow provide one of components to the chemical difference in the peat soil between coniferous and broadleaf forests.

On the other hand, the differences along the gradient from the tree base to the site 50 cm from the base (comparison between N and F sites) was significant only for limited parameters and the tendency was not consistent (Table 2). An unclear gradient of chemical parameters from the stem base in the peat soil stands was the common observation in the three species. Gesper (1970) who investigated radioisotope accumulation in soils around beech trunks, speculated that stemflow water on the slope (ca. 11°) was likely to flow vertically and also contributed significantly to internal downslope flow. In Cape Ochiishi Mire, the stemflow movement in the high water content of the peat could be more slow, because three species in the mire established on the flat topography (< ca. 1°). This would be due to the fact that the chemicals in stem flow would be diluted by the abundant peat pore water. Moreover, proton that was produced by dissolution from humic substances (Haraguchi et al. 2003; Nishijima and Nakata 2004) and ion exchange with base cations in the precipitation (Gorham 1956) was dominant buffer reactions in the peat soil. The significant differences in the chemical environments particularly soil pH between stem base and distal areas appeared interspecies difference rather than the surface soil. This

result indicated that effect of stemflow not only determined the soil close to the stem but also the soil extended the area under the canopy. Thus, it is presumed that stemflow provide the best site both close to the site and under the canopies and play an important role in promoting the natural regeneration.

Peat pore water at the peat surface had the lowest and that at the 60 cm depth had almost the highest score on the second principal component axis. This high score for the second principal component was due to the high concentrations of NO_3^- and NH_4^+ and the low concentration of H^+ . Accumulation of NO_3^- and NH_4^+ under the high pH condition in the subsurface of the peat layer would be due to the decomposition of organic substances in the subsurface of the peat layer. The spatial variability of the peat soil chemistry was affected by stemflow chemistry, would be an important factor in the decomposition of peat within the peatland forest.

Thus we can conclude that the effects of stemflow on the peat pore water chemistry are clearly seen only at the stem base in the peat forest in the mire and the peat pore water around the stem base of a tree has particular chemical properties specific to each species; however, the gradient of the chemical environment from the stem base to the area beyond the canopy was not significant in the peatland forest. The peat pore water chemistry under the canopy would be mainly controlled by the chemical processes within the peat. The spatial heterogeneity of chemical environment between microsites within peatland forests would be contributed indirectly through the control of microorganism activity, nutrient regeneration and the understory vegetation mediated the surface water and the stemflow of the dominant canopy trees. In inundated soil in peatland, the chemical environments of the peat soil around the tree stand appear species specificity. Therefore, the maintenance of chemical environment which focus on species-specific needs for the conservation of the peatland forests, it means that the hydrological change such as large fluctuation of groundwater level diminishes.

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